

TIME-RESOLVED SPECTROSCOPY OF MID-IR LASER STRUCTURES

Thomas F. Boggess

The University of Iowa

Collaborators:

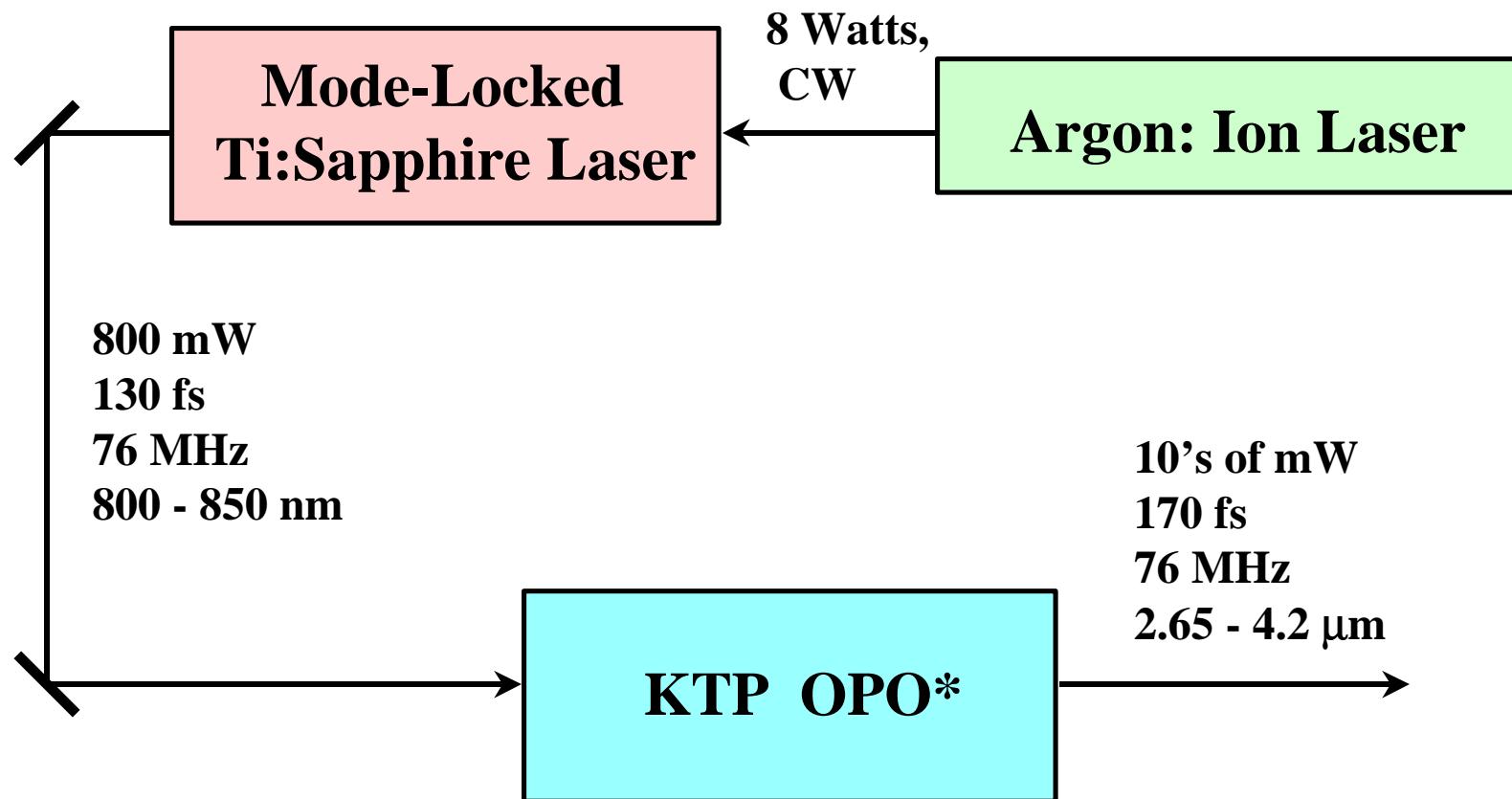
Michael Flatté, Chris Grein (Theory)
Tom Hasenberg (MBE Growth)
Winston Chan (Device Processing)

Students:

Scott Anson, Bennett Brown, Brian Carter, Peter Day, Der-Jun Jang,
Dan Magarrell, Jon Olesberg, Ed Shaw, Chaowen Yu, Lin Zhang

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Ultrafast MWIR Spectroscopic Source

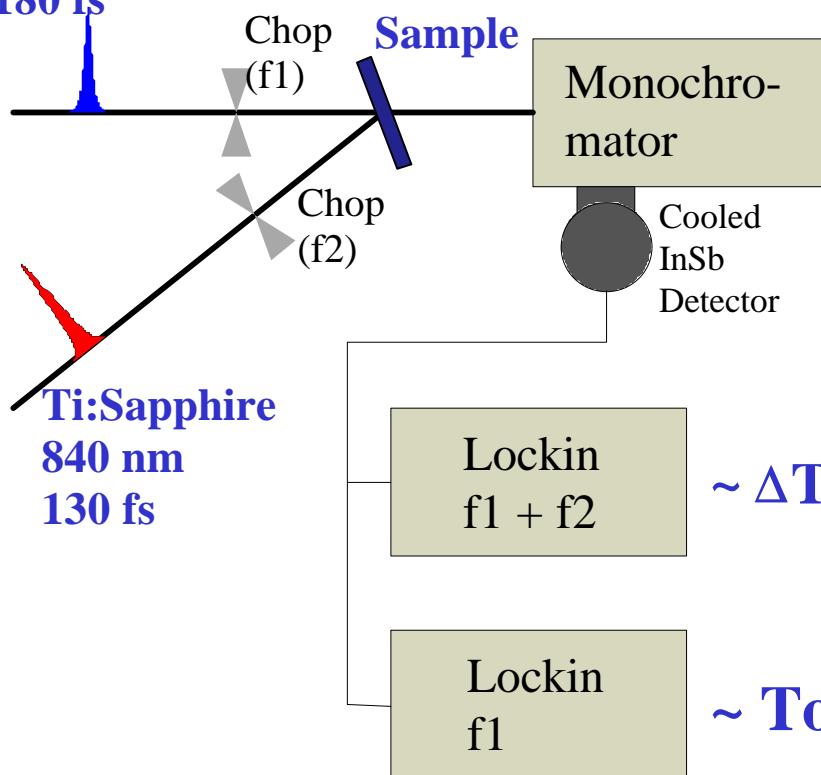


*S. W. McCahon, et al., Optics Letters, 20, 2309 (1995)

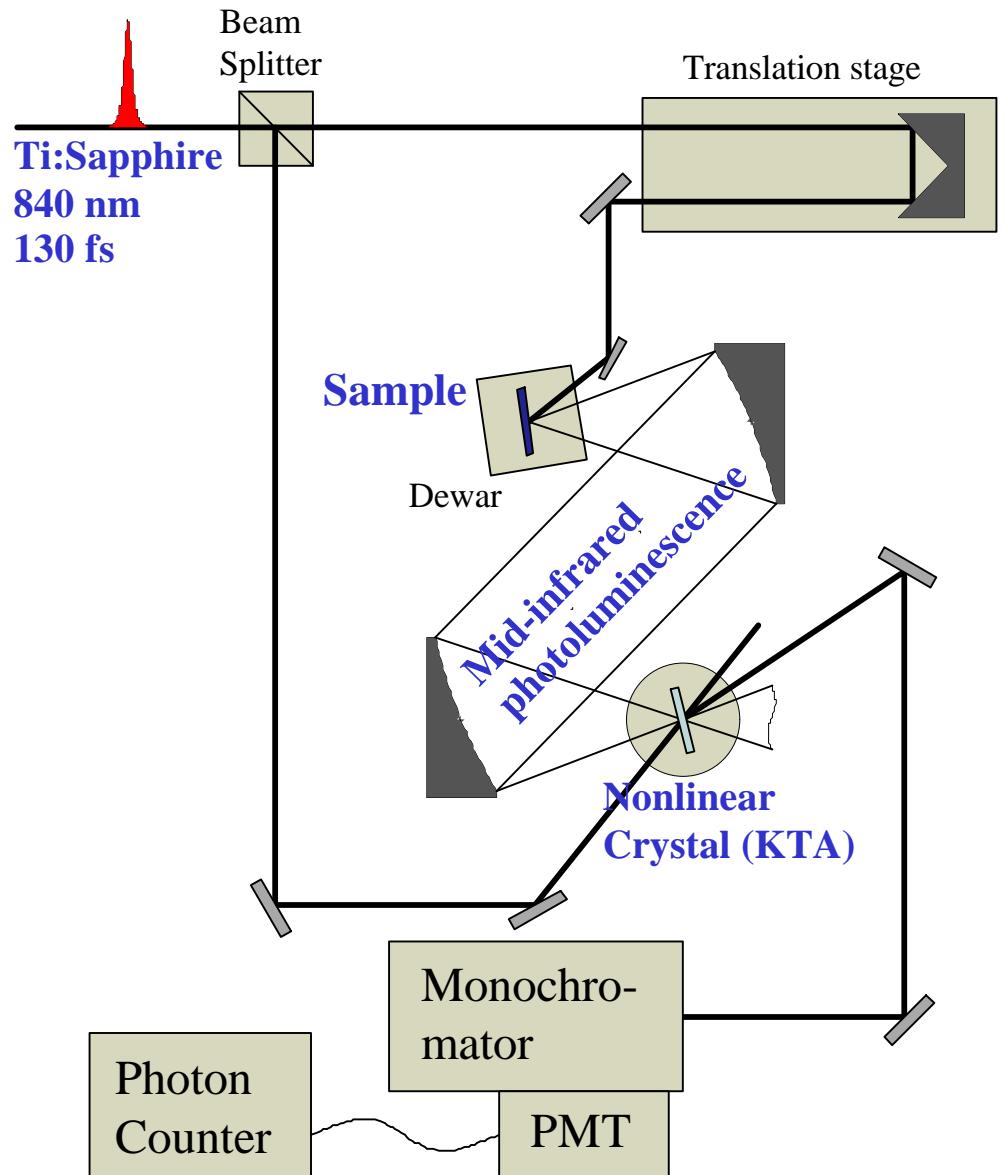
Pump-Probe

OPO Idler
2.6 - 4.4 microns

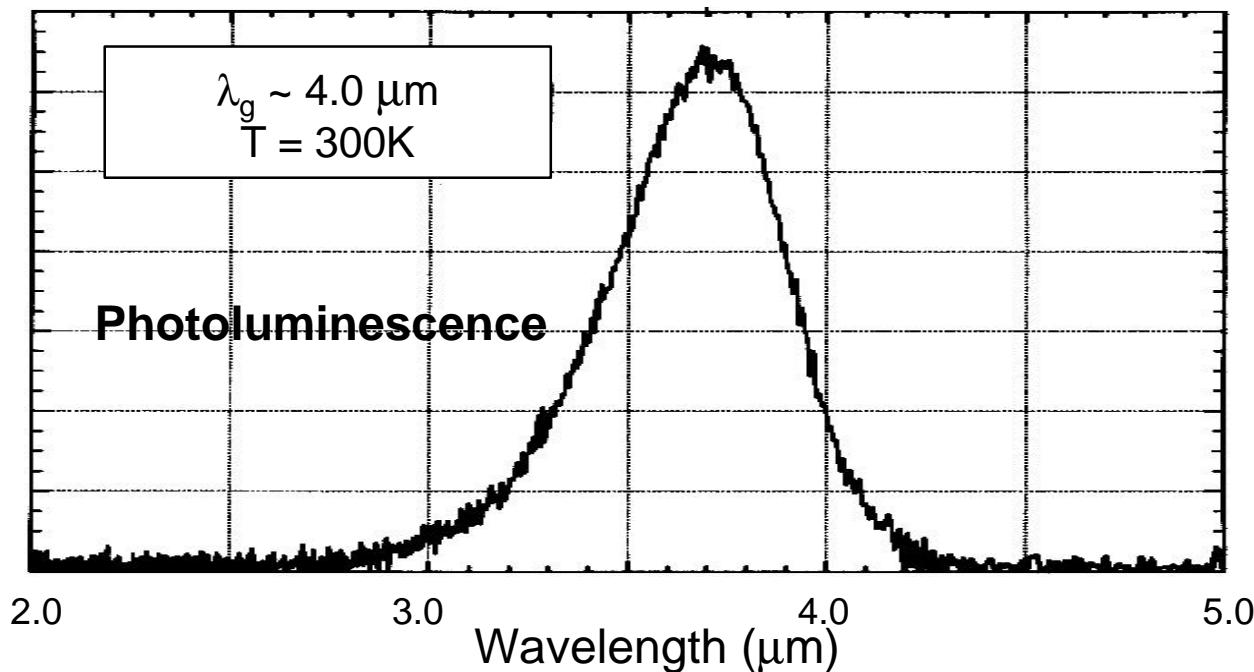
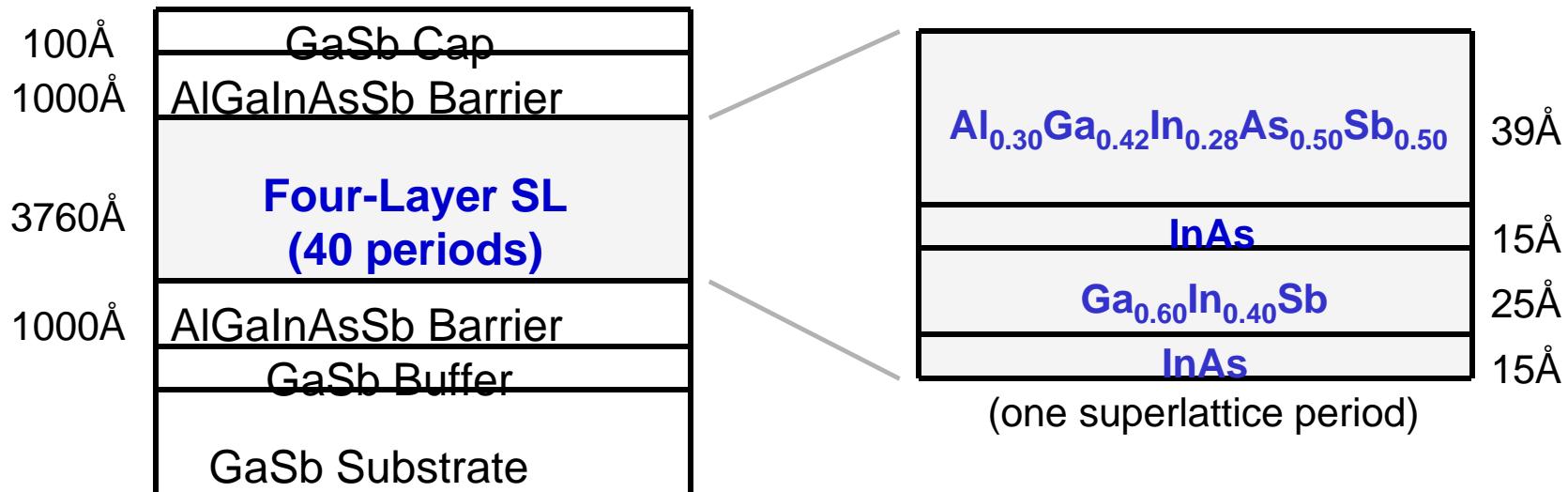
180 fs



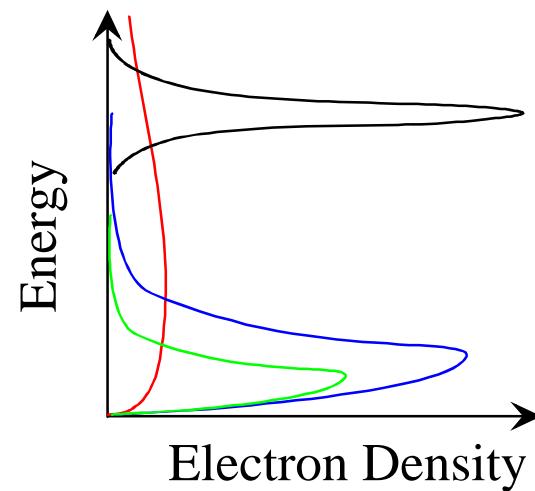
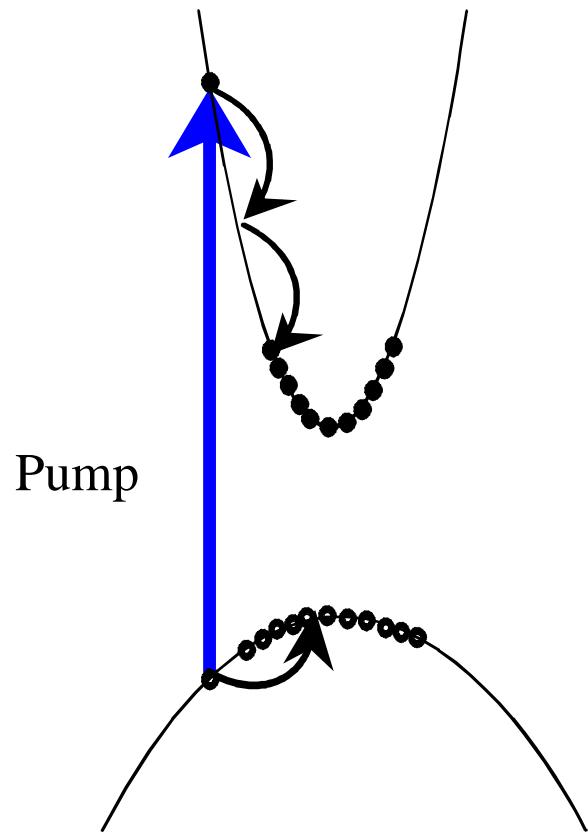
Photoluminescence Upconversion



Sample Structure



ULTRAFAST OPTICAL EXCITATION



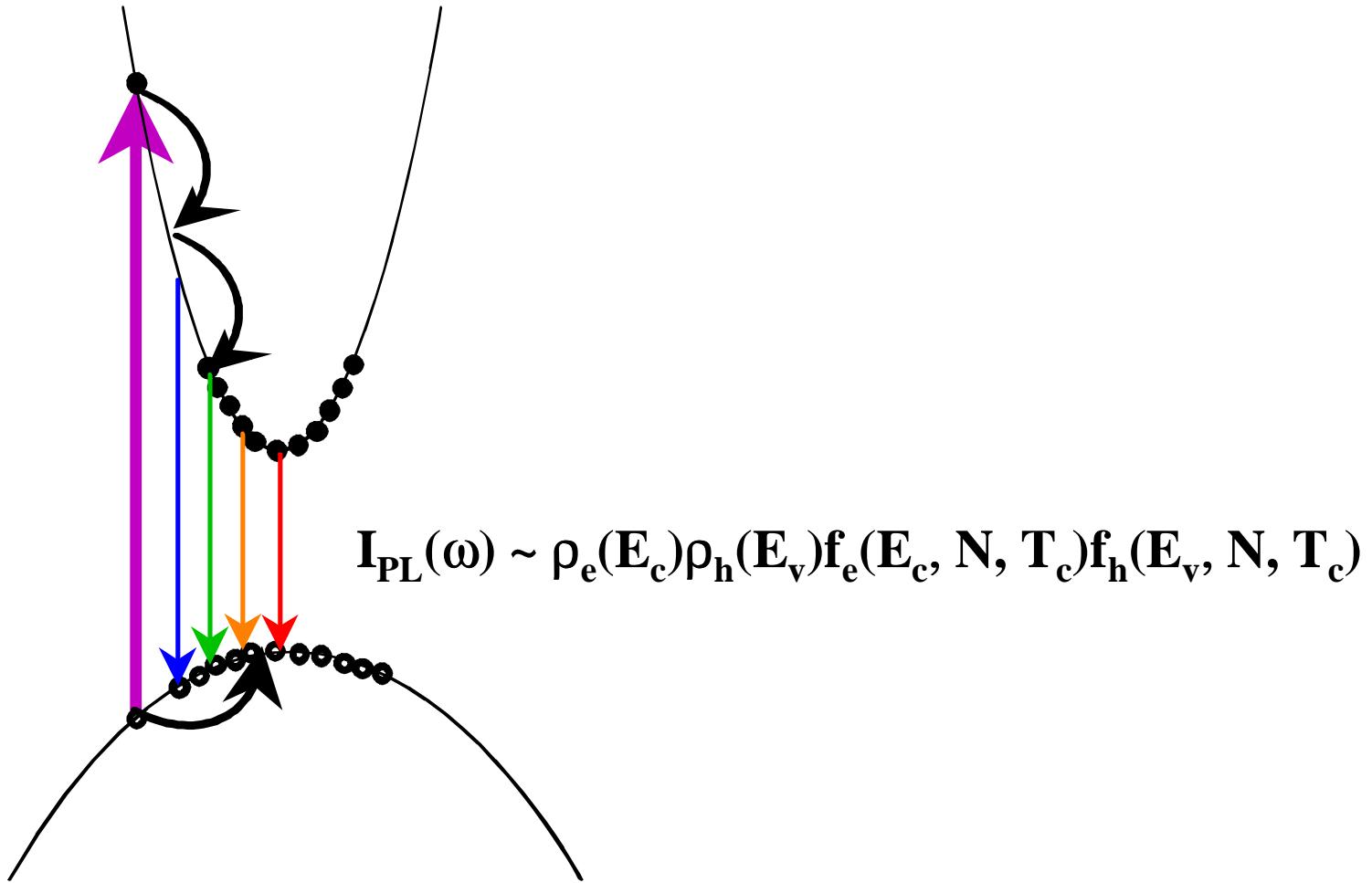
$t < 100 \text{ fs}$; nonthermalized

$t \sim 1 \text{ ps}$; $T_c \gg T_L$

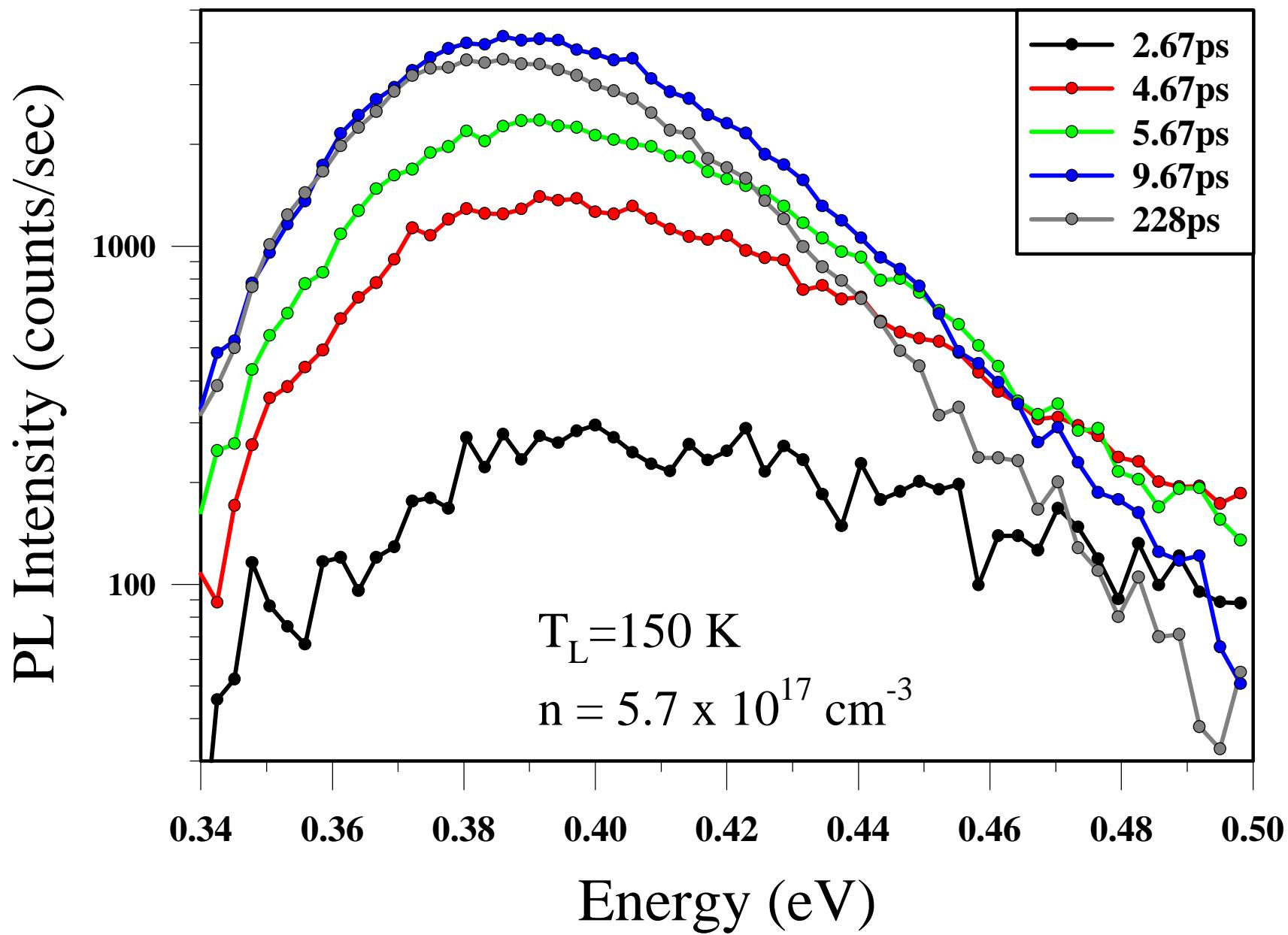
$t \sim 10 \text{ ps}$; $T_c \approx T_L$

$t \sim 1 \text{ ns}$

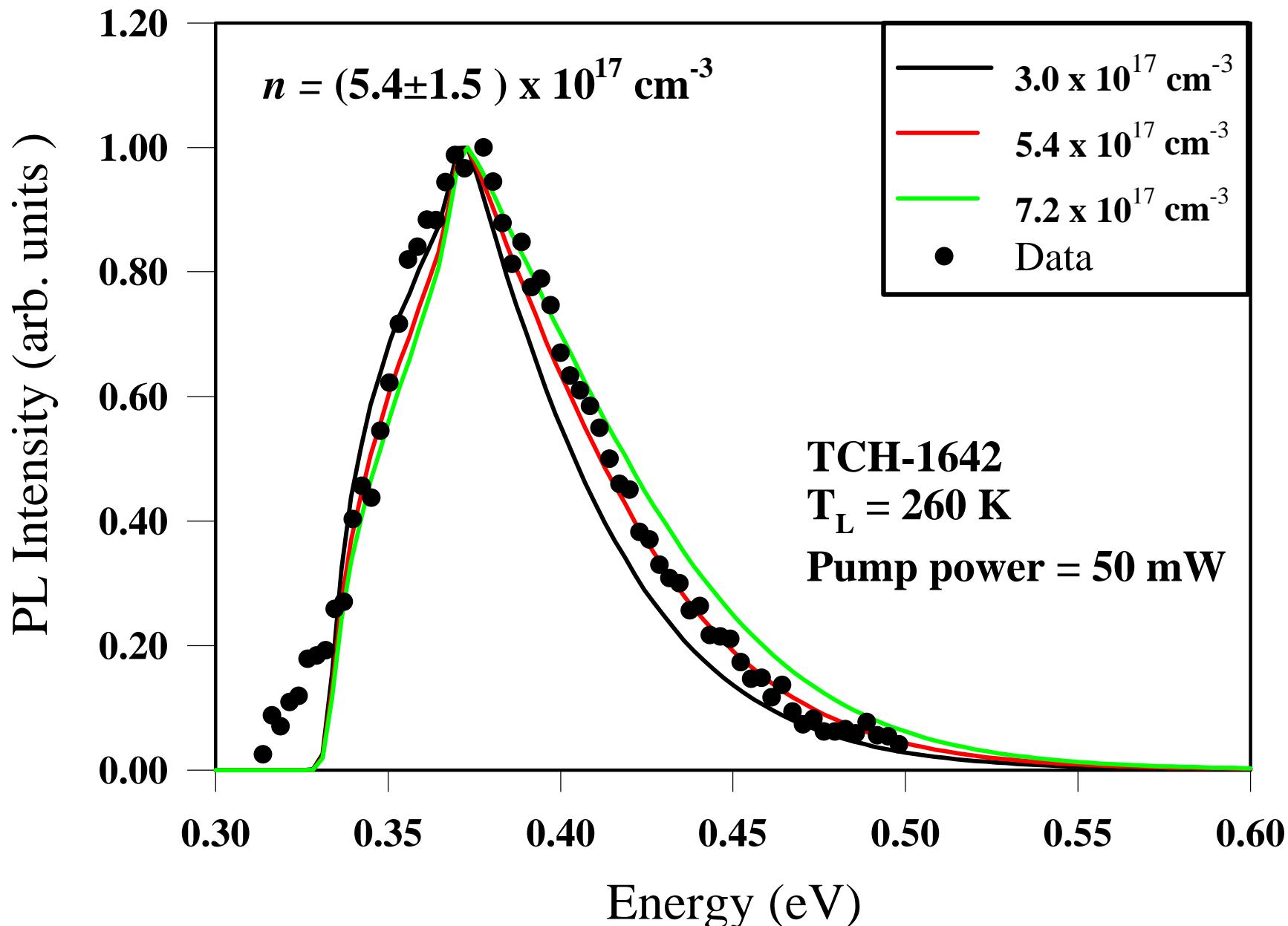
HOT-CARRIER RELAXATION AND RECOMBINATION FROM PHOTOLUMINESCENCE



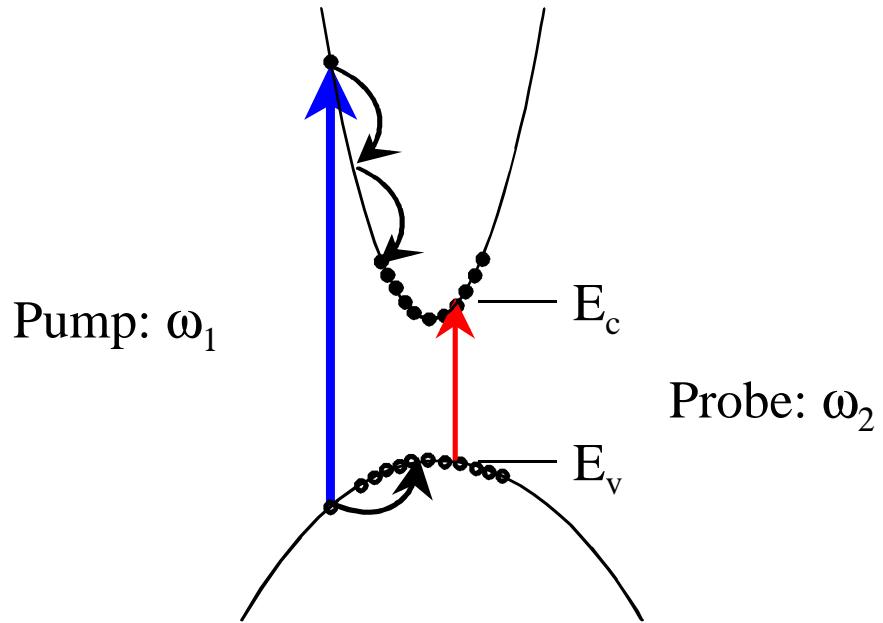
Time-Resolved PL Spectra of TCH-1642



Carrier Density Calibration From Time-Resolved PL Spectrum



BAND FILLING CONTRIBUTION TO DIFFERENTIAL TRANSMISSION



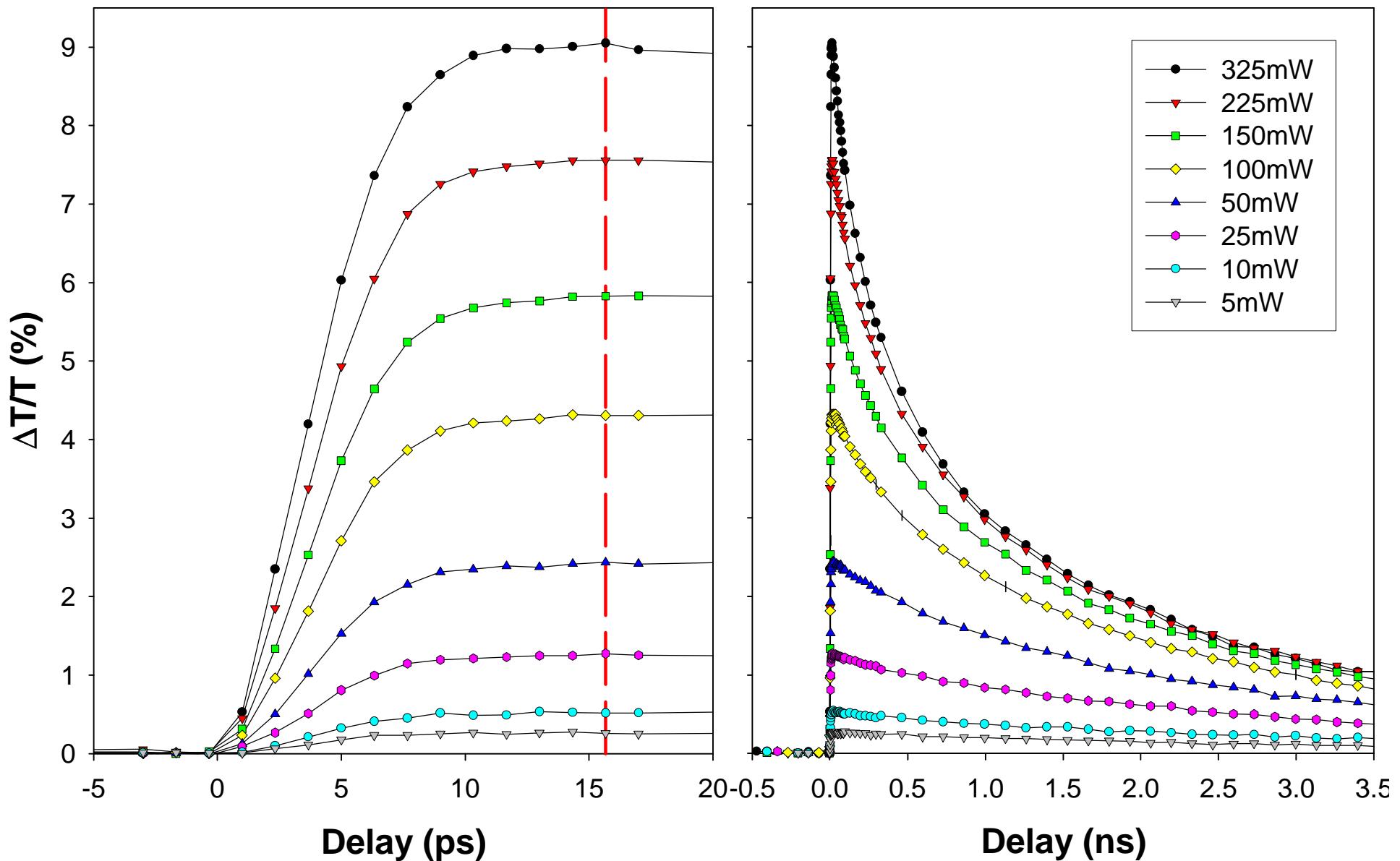
$$\alpha(\omega_2) = \alpha_o(\omega_2) + \Delta\alpha(\omega_2)$$

$$\Delta\alpha(\omega_2) = -\alpha_o(\omega_2)[f_e(E_c, N, T_c) + f_h(E_v, N, T_c)]$$

$$\Delta T/T (\omega_2) \equiv -\Delta\alpha(\omega_2) L$$

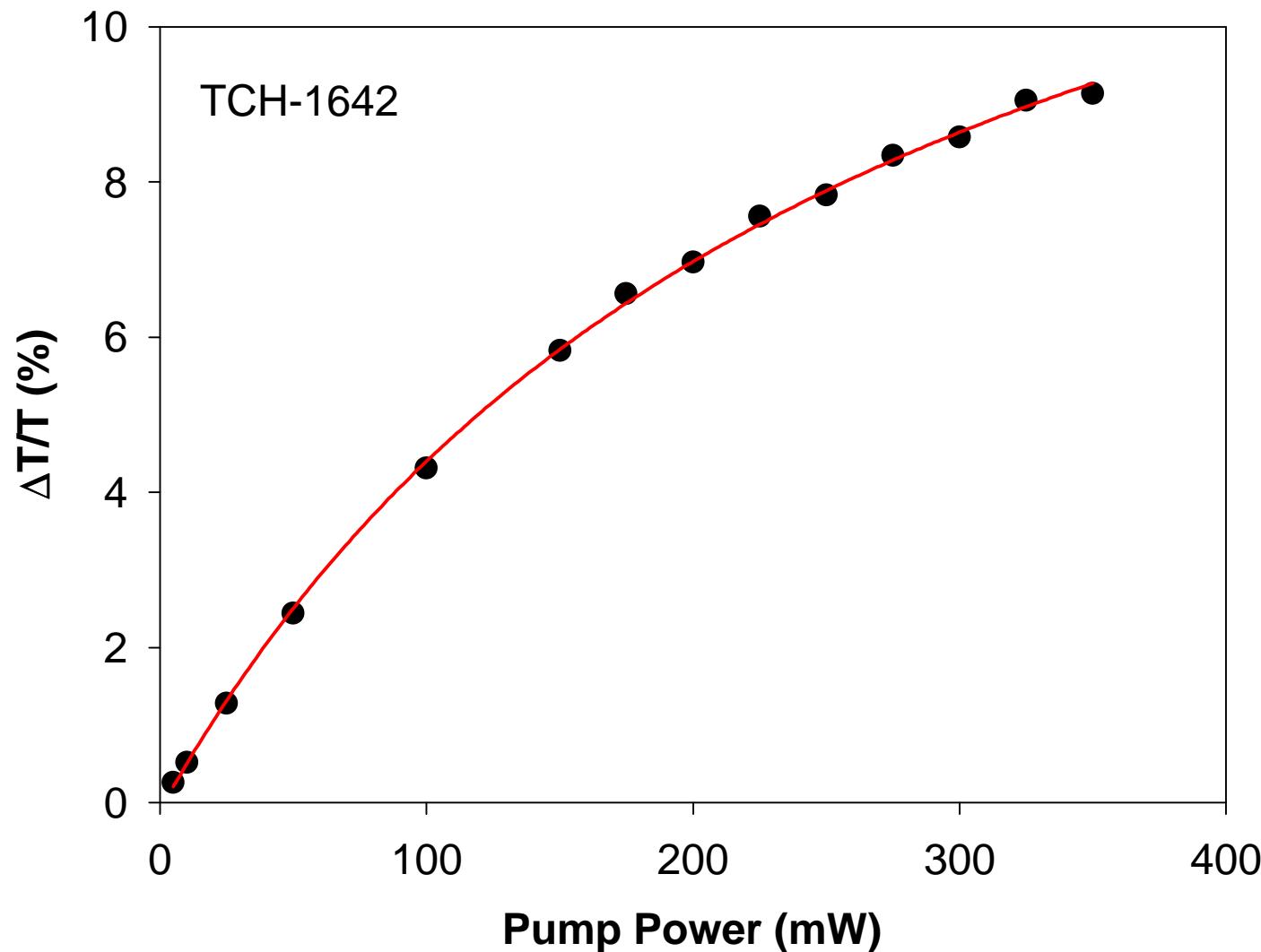
Differential Transmission TCH1642

300K, $\lambda_{\text{probe}} = 3.55\mu\text{m}$

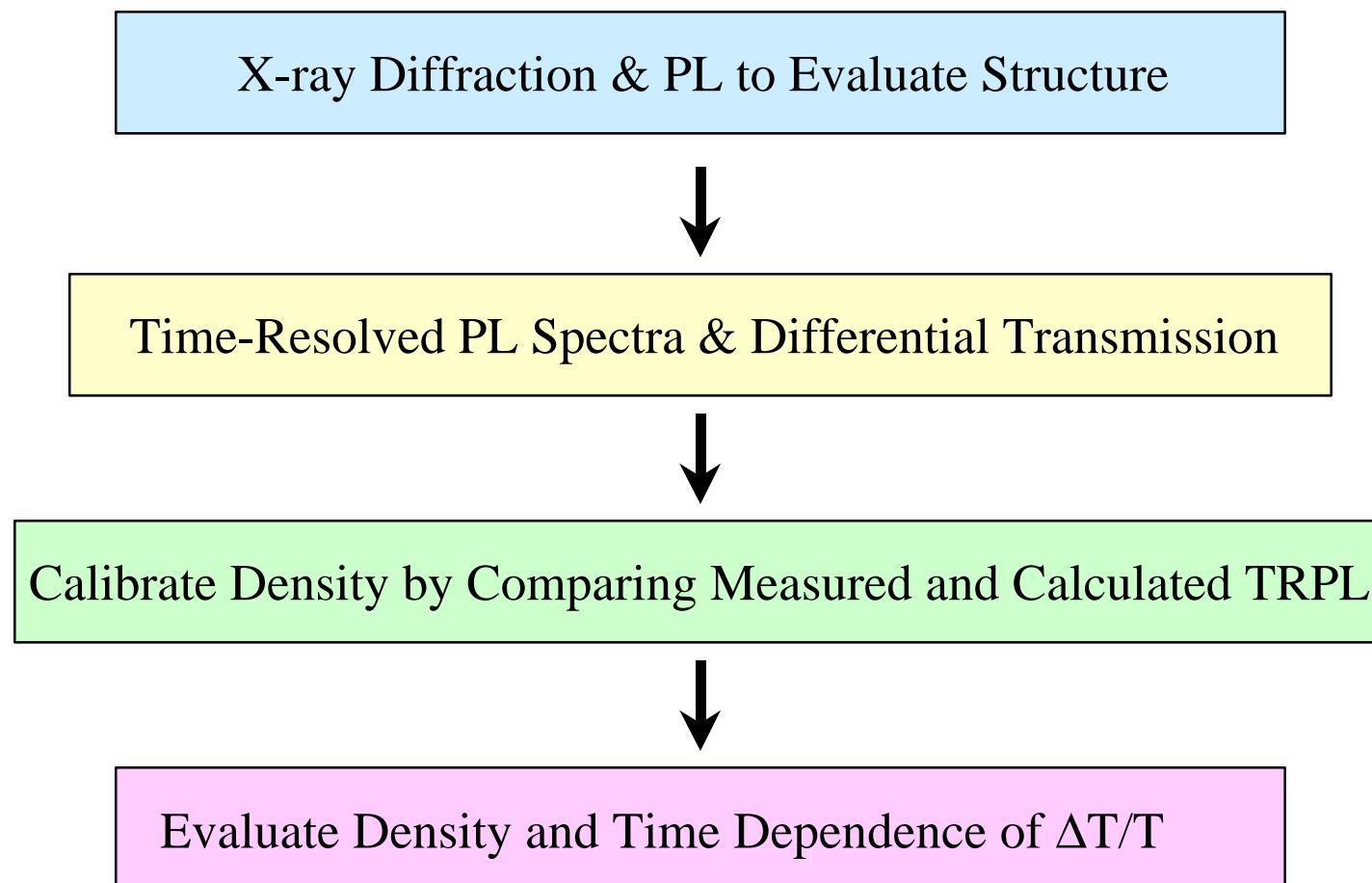


Saturation of Peak Differential Transmission

300K, $\lambda_{\text{probe}} = 3.55\mu\text{m}$



Analysis of Auger Recombination



Analysis of Differential Transmission Data

Relate $\Delta T / T$ to Density Dependent Recombination Rate

$$R(n) = \frac{1}{n} \frac{dn}{dt} = \frac{1}{n} \frac{dn}{d(\Delta T / T)} \frac{d(\Delta T / T)}{dt}$$

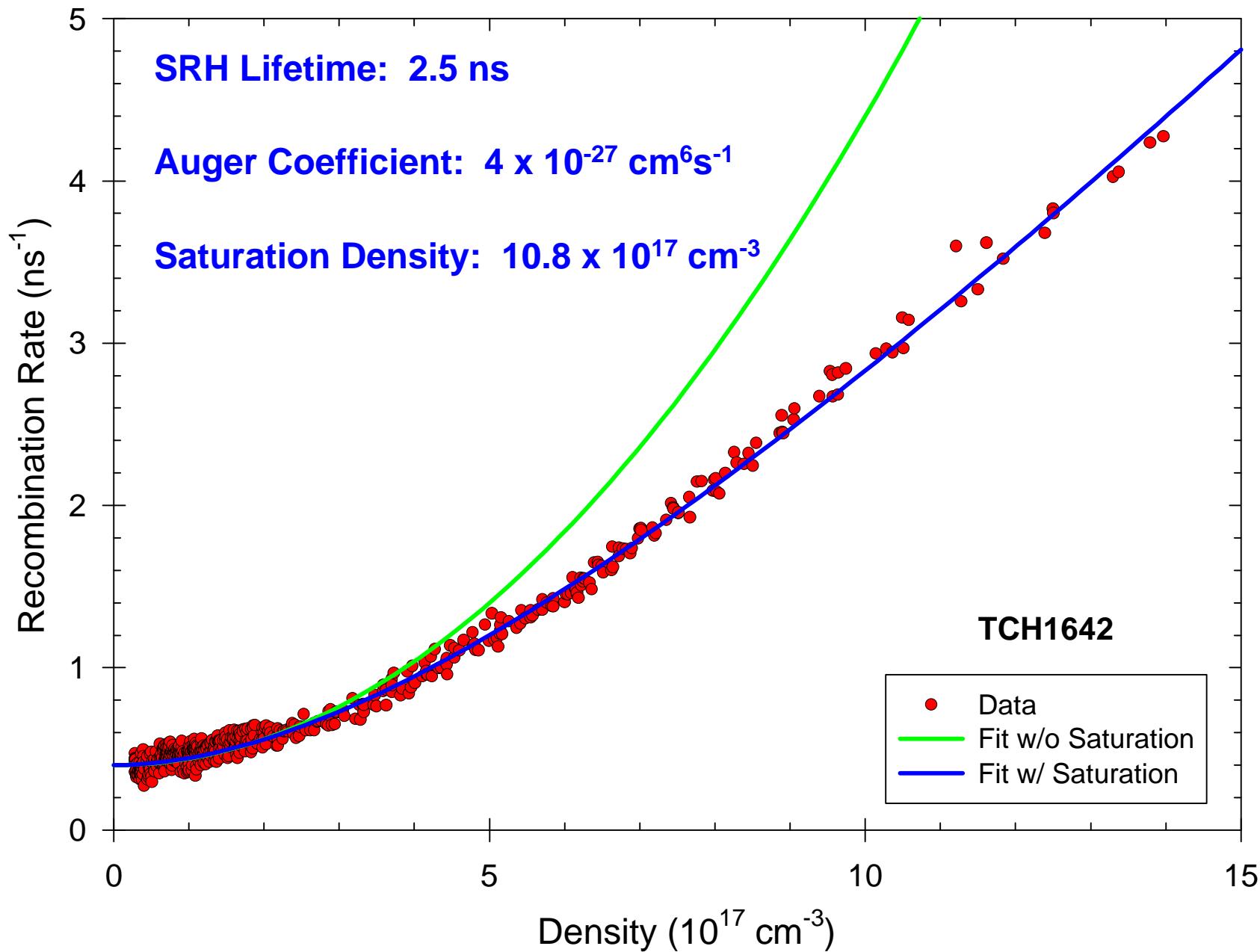
Fit Data Using Phenomenological Rate Equation - Use Theoretical
B(n) and A and C(n) as fitting parameters

$$R(n) = -A - B(n)n - C(n)n^2$$

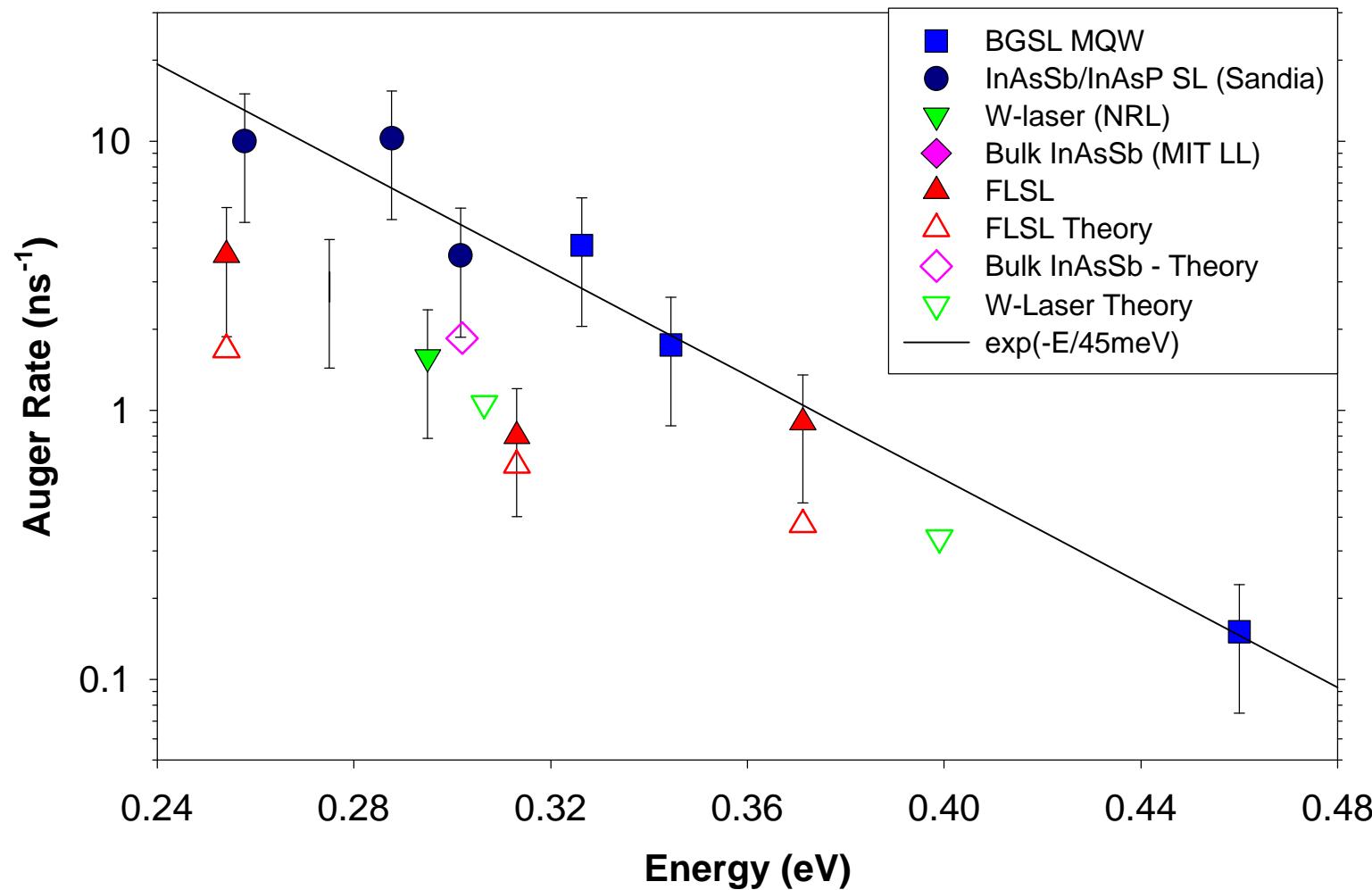
Assume Simple Saturation Form for Auger Coefficient

$$C(n) = \frac{C}{(1 + n / n_{sat})}$$

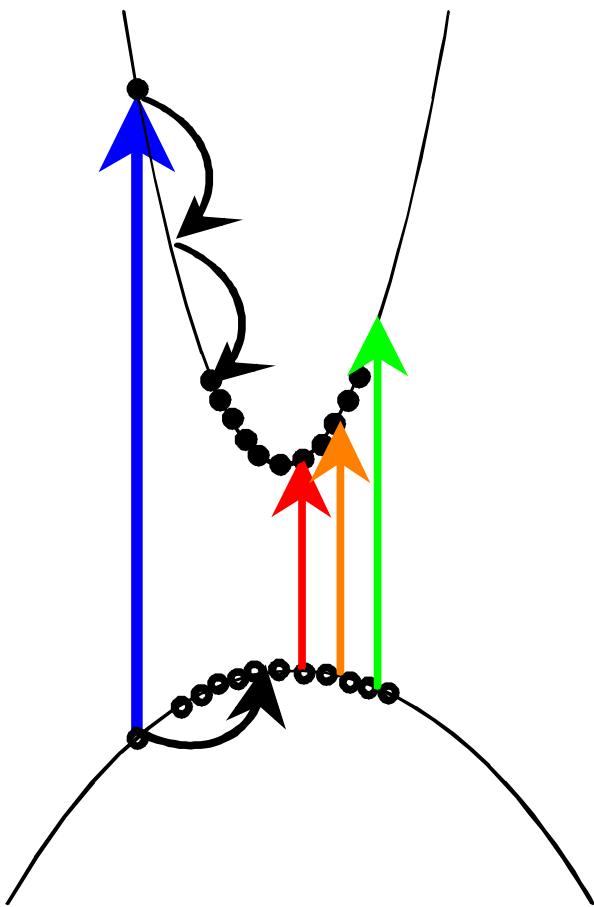
Recombination Rate Analysis



Summary of 300K Auger Rates at $5 \times 10^{17} \text{ cm}^{-3}$ Measured Using All-Optical Techniques

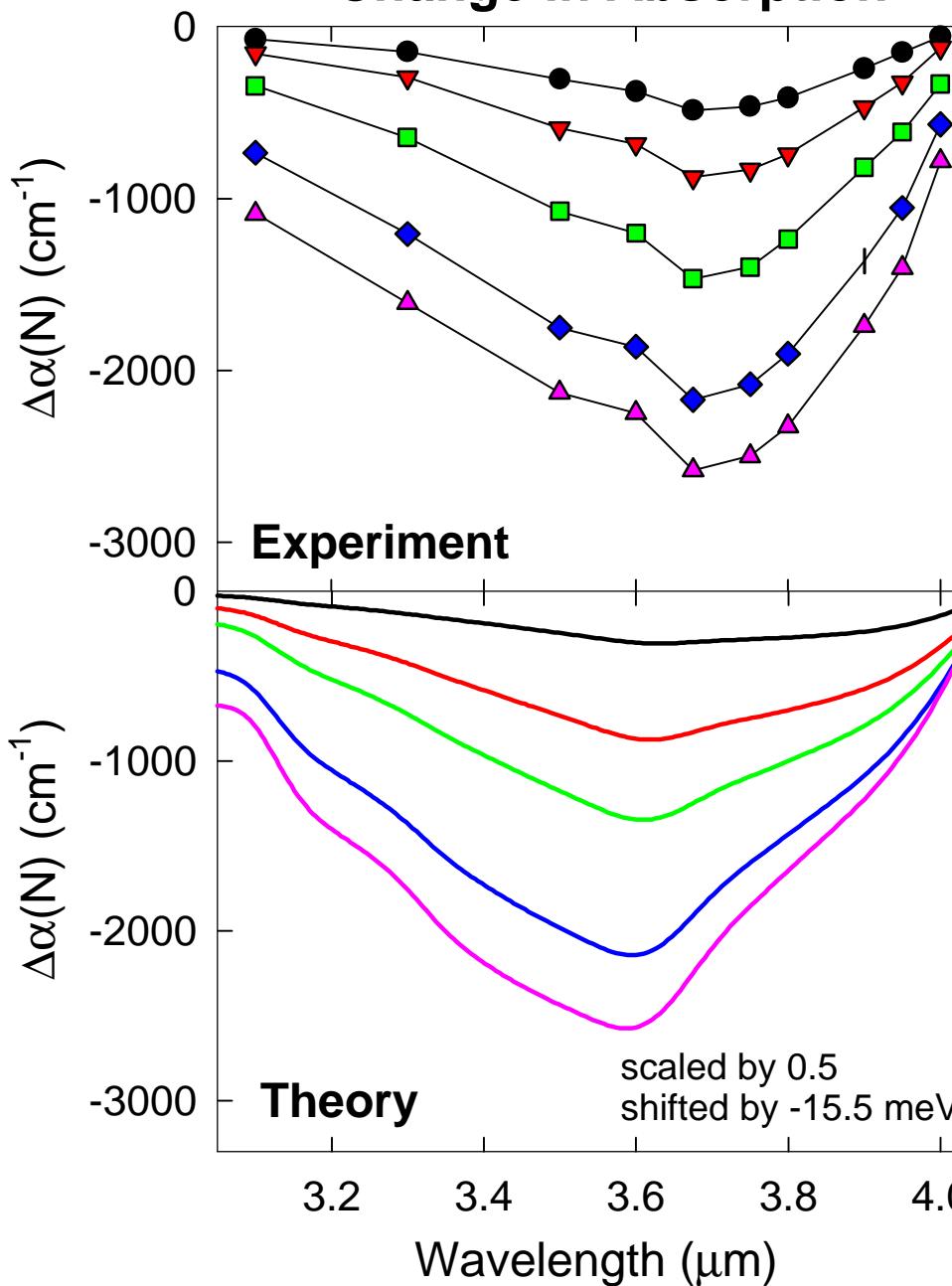


CARRIER-DENSITY-DEPENDENT ABSORPTION SPECTRA

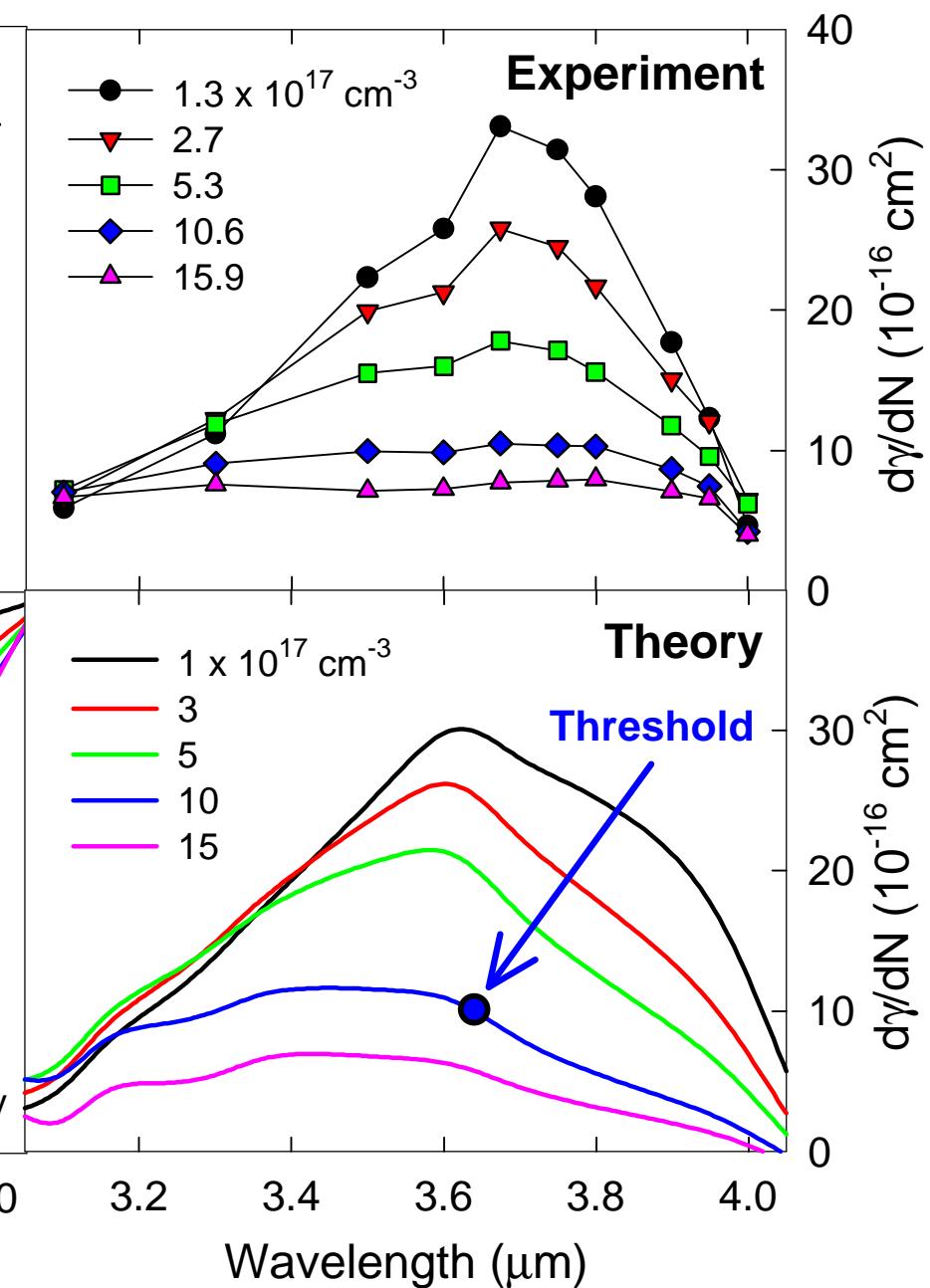


Use tunability of OPO to
measure $\Delta\alpha$ as a function
of ω

Density-Dependent Change in Absorption

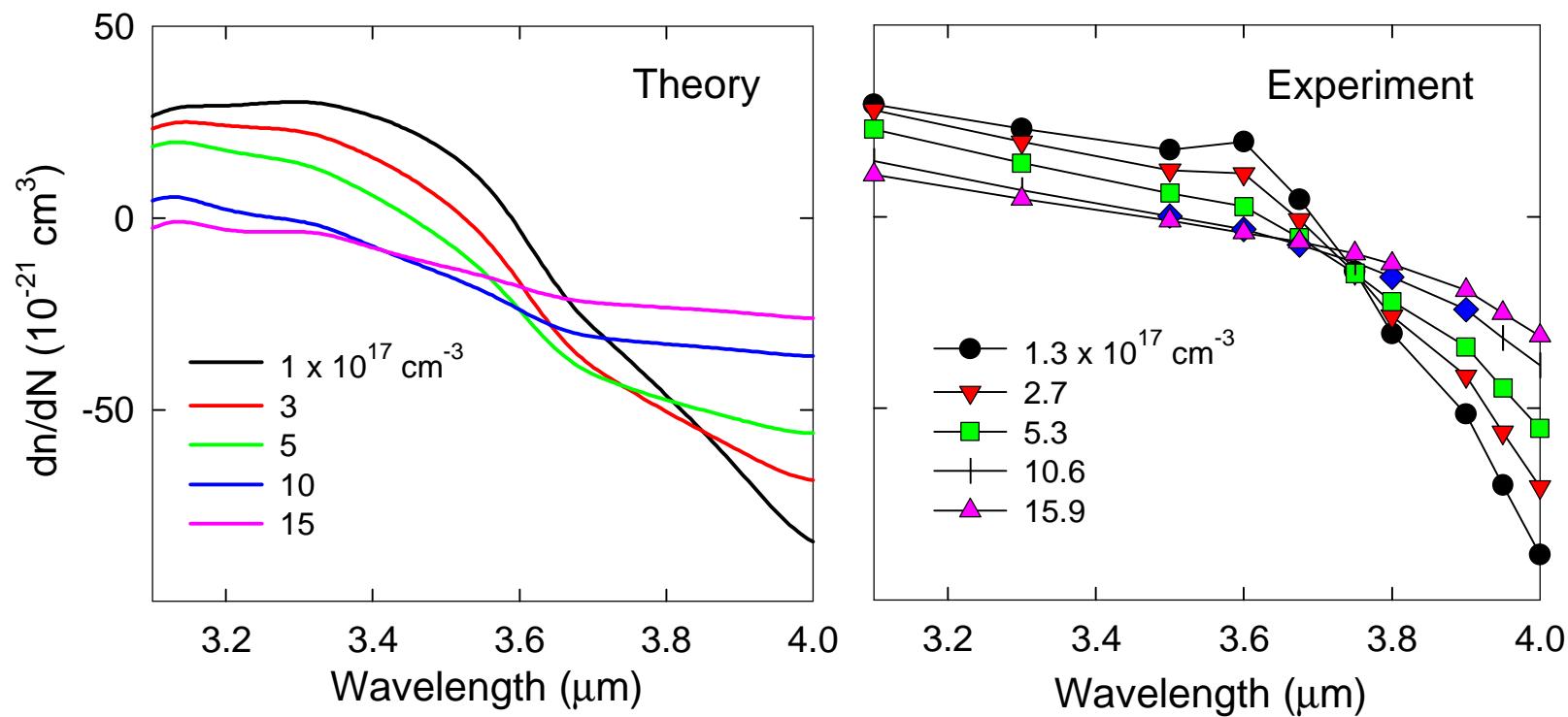


Differential Material Gain



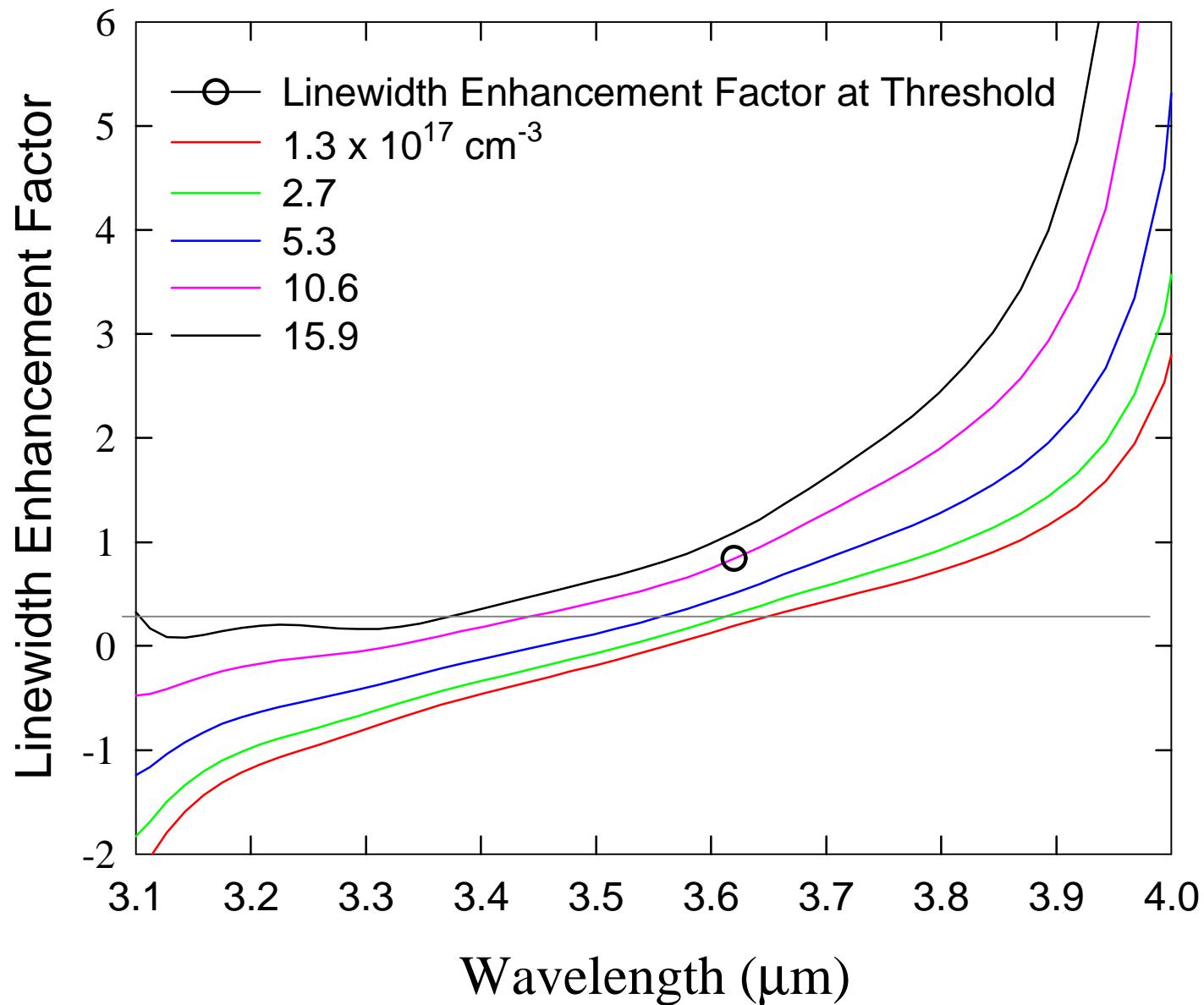
Differential Refractive Index

TCH-1642, 300K



Linewidth Enhancement Factor

TCH-1642, 300K



Broad-band Differential Transmission Upconversion

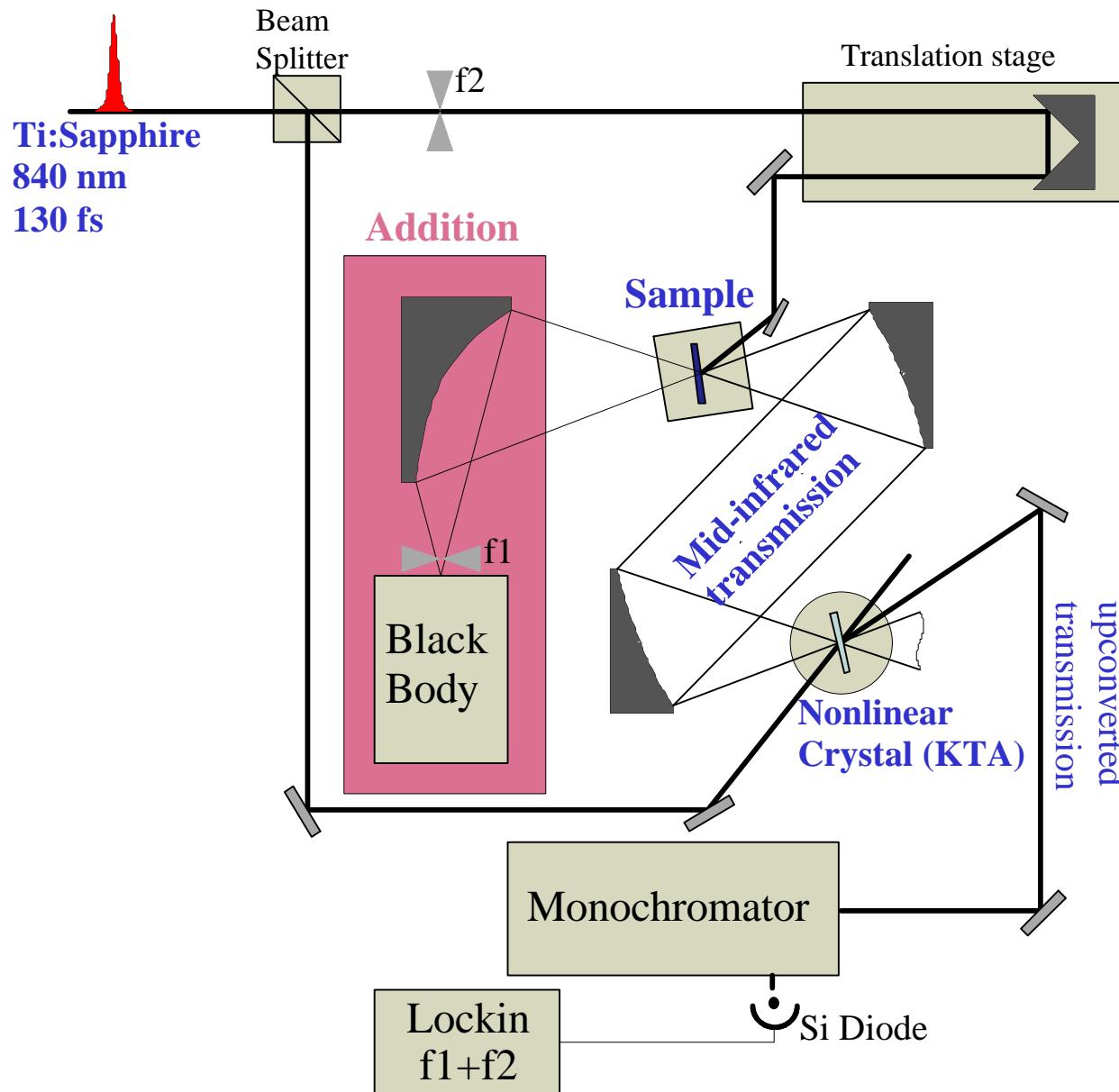
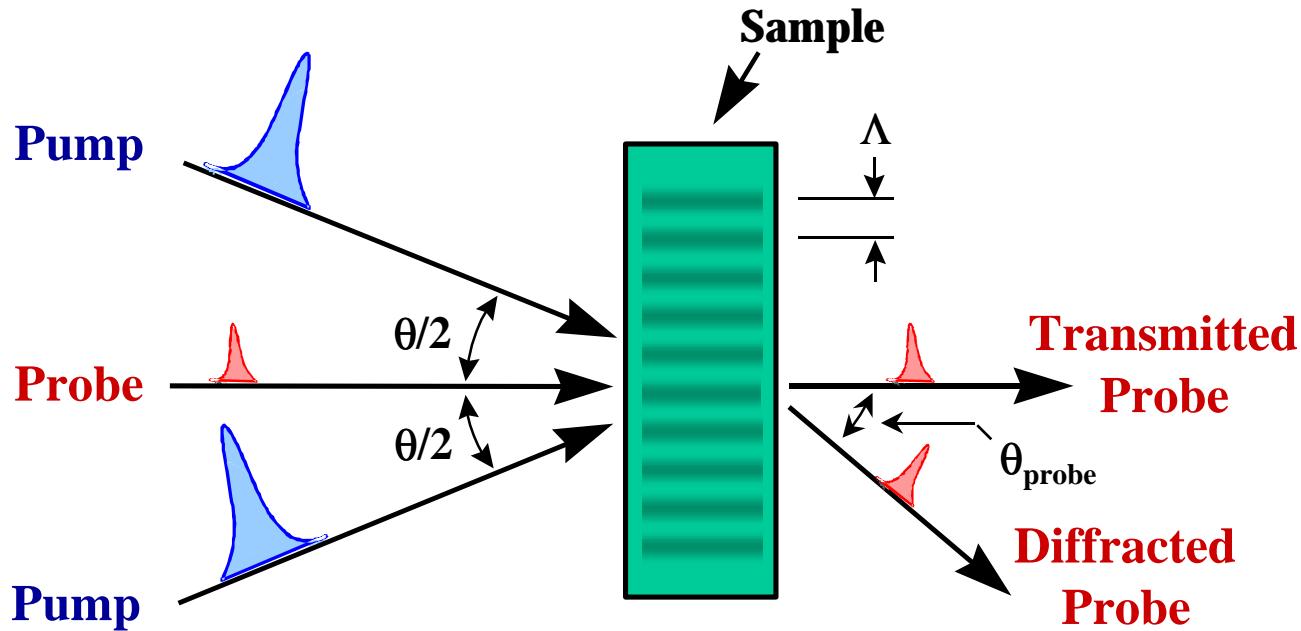


Photo-Generated Transient Grating Experiment



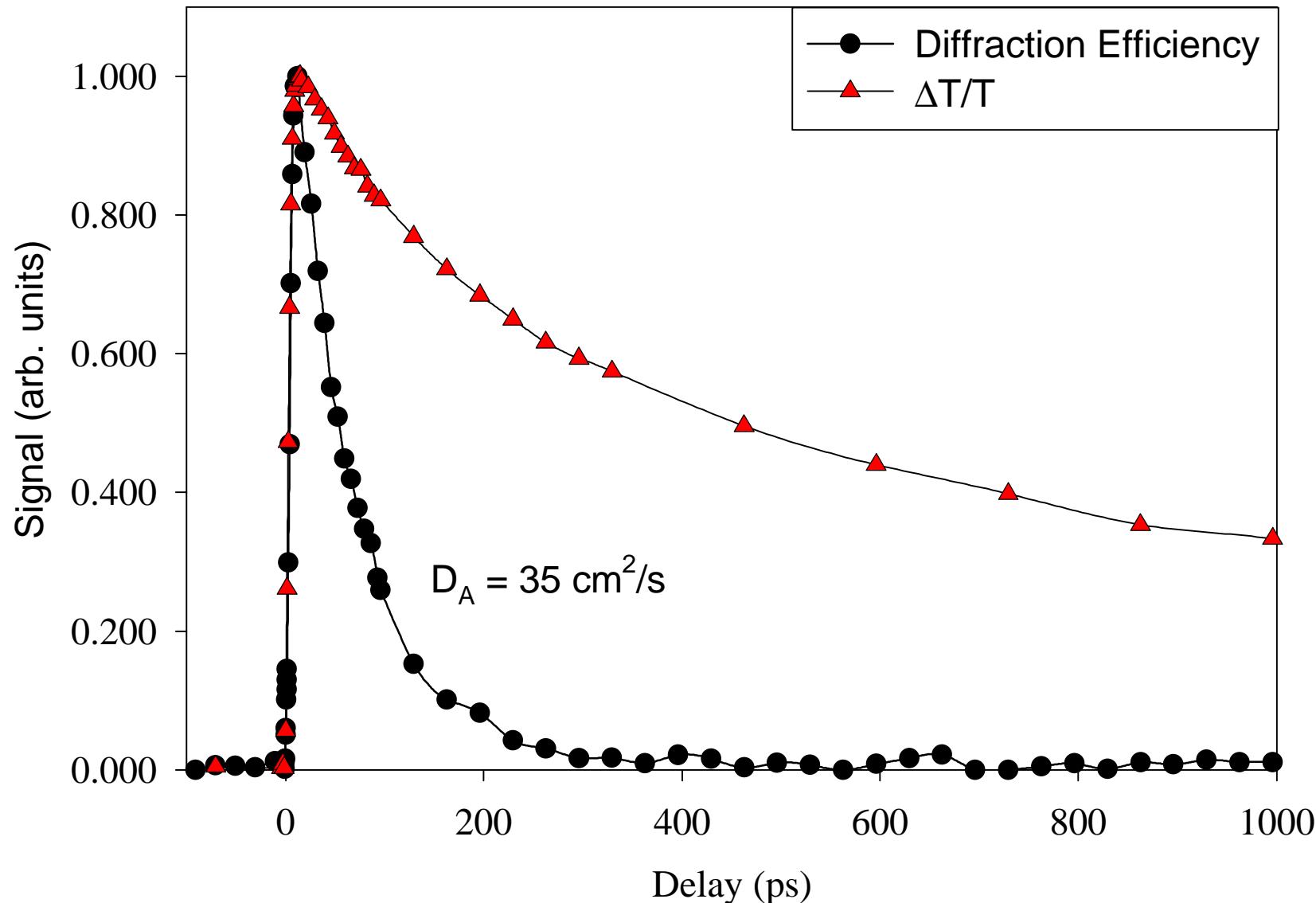
Diffraction Efficiency:

$$\eta(t) = I_{\text{diff}}/I_{\text{inc}} = m^2 |J_1(2\pi \Delta n L / \lambda + i \Delta \alpha L / 2)| \exp(-\alpha L) \exp(-2t/\tau_g)$$

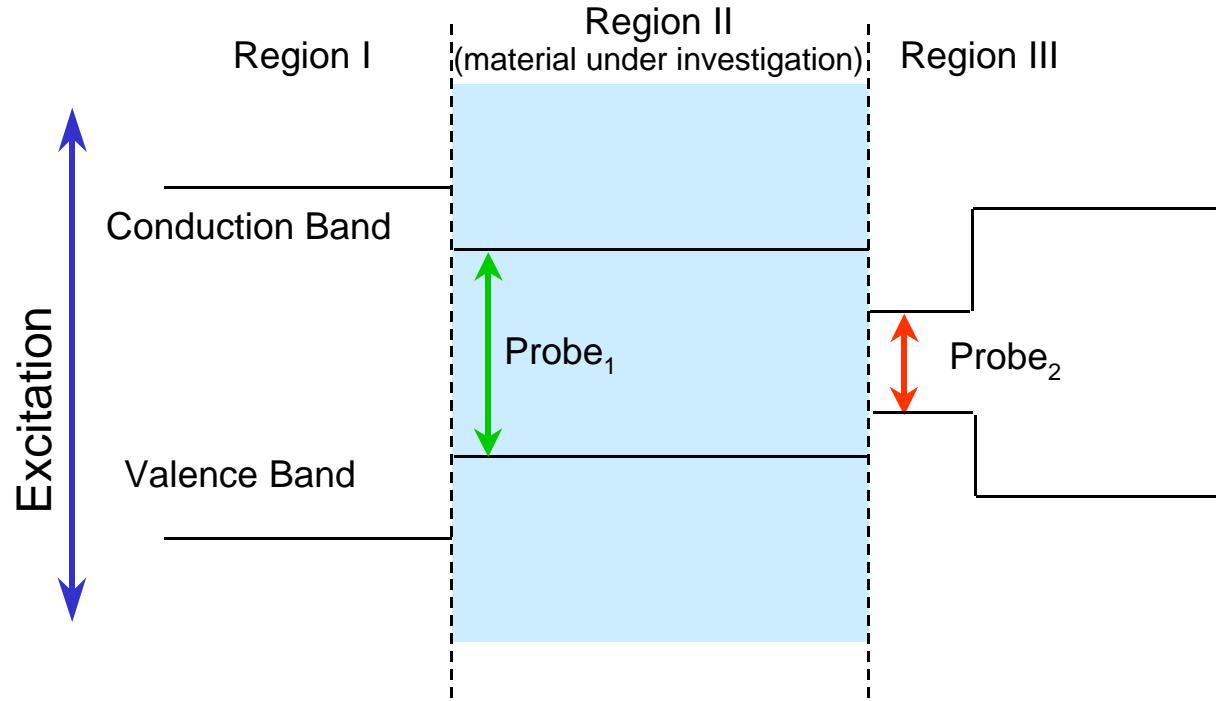
$$1/\tau_g = 1/\tau_d + 1/\tau_{R(n)}$$

Decay of Differential Transmission and Diffraction Efficiency

TCH-1642, 300K, 6 μ m grating period, peak density $\approx 1.5 \times 10^{18} \text{ cm}^{-3}$



Vertical Transport Using Time-Resolved PL



Measure relative delay between onset of PL from Region II and Region III Using PL Upconversion

Summary & Conclusions

Ultrafast MWIR optical techniques have been used to measure the electronic and optical properties of various Sb-structures

- hot carrier relaxation
- carrier recombination
- gain, refractive index spectra, linewidth enhancement factors
- Intersubband resonances
- carrier transport (in-plane and vertical)

Four-layer Type II superlattices

- suppressed Auger recombination
- saturation of the Auger rate
- large differential gain
- small linewidth enhancement factors
- large gain to current ratios
- good agreement with superlattice K•p theory

Ultrafast techniques can be valuable tools for MWIR laser design